

TITLENICKEL CATALYZED ADDITION OF -NH- CONTAINING  
COMPOUNDS TO VINYL AND ARYL HALIDESFIELD OF INVENTION

- 5 The present invention generally relates to a process for the production of enamides, enamines, aryl amines and aryl amides by coupling a vinyl halide or aryl halide with an -NH- or -NH<sub>2</sub>- containing compound using a nickel catalyst.

BACKGROUND OF THE INVENTION

- 10 Enamines and enamides are useful synthetic intermediates of use to the agrochemical, pharmaceutical, and other fine chemical industries. Previously, enamine and amide compounds have been prepared by: a) addition of amine or amide to an epoxide followed by dehydration; b) direct addition of -NH- containing compounds to alkynes; c) Curtius reaction of  $\alpha,\beta$ -unsaturated azides; or d) Beckmann rearrangement of  $\alpha,\beta$ -unsaturated oximes. Each of these  
15 methods requires several synthetic steps for the synthesis of enamides or enamines and some suffer from lack of regioselectivity.

- Prior to the instant invention, it was known in the art that Cu(I) compounds could be used as stoichiometric reagents to effect the coupling of aryl bromides and -NH- containing compounds. This chemistry was extended to  
20 vinyl bromides by Ogawa et al (Ogawa, T.; Kiji, T.; Hayami, K.; and Suzuki, H.; Chemistry Lett. 1991, p. 1443) who reported the coupling of vinyl bromides with the potassium salt of an acidic amide in the presence of a stoichiometric amount of copper iodide to provide enamides.

- The coupling of aryl halides and an -NH- containing compound has also  
25 been accomplished catalytically using a base and a palladium (Pd) catalyst. This catalyst system, however, is not known or reported to couple vinyl halides and -NH- containing compounds. Kosugi, M.; Kameyama, M.; and Migita, T.; Chem Lett., 1983, p. 927 reported the Pd catalyzed coupling of tin amides and aryl halides to form aryl amines. Several other references have disclosed the Pd  
30 catalyzed coupling of amines and aryl halides in the presence of a strong base to form aryl amines (e.g., see Paul, Frederic; Patt, Joe; and Hartwig, John F.; J. Am. Chem. Soc., 1994, 116(13), pp. 5969-70; Louie, Janis; and Hartwig, John F.; Tetrahedron Lett., 1995, 36(21), pp. 3609-12; Hartwig, John F.; and Paul, Frederic; J. Am. Chem. Soc. 1995, 117(19), pp. 5373-4; Wolfe, John P.;  
35 and Buchwald, Stephen L.; J. Org. Chem., 1996, 61(3), pp. 1133-5; Guram, Anil S.; Rennels, Roger A.; and Buchwald, Stephen L.; Angew. Chem., Int. Ed. Engl., 1995, 34(12), pp. 1348-50).

A. J. Arduengo, et al., J. Am. Chem. Soc., vol. 113, p. 361-363 (1991) and A. J. Arduengo, et al., J. Am. Chem. Soc., vol. 114, p. 5530-5534 (1992) report the synthesis of (1,3-disubstitutedimidazol-2-ylidene) carbenes.

- 5 The present invention provides for the use of a nickel catalyst complex rather than the more expensive palladium catalysts of the prior art and allows for the one step coupling of vinyl halides in addition to aryl halides. Other objects and advantages of the present invention will become apparent to those skilled in the art upon reference to the detailed description which hereinafter follows.

#### SUMMARY OF THE INVENTION

- 10 The present invention relates to a process for the production of unsaturated nitrogen containing compounds comprising: reacting a compound containing an -NH- or -NH<sub>2</sub>- functional group next to a carbon sp<sup>2</sup> center with a compound of the formula



- 15 where X is either chloride, bromide or iodide;  
R<sub>1</sub> is either hydrogen, an alkyl group, or an aryl group;  
R<sub>2</sub> is independently selected from hydrogen, methyl or trimethylsilyl; and  
R<sub>3</sub> is an optionally substituted aryl group;

- 20 in the presence of a stoichiometric amount of a base and a catalytic amount of a catalyst precursor composition comprising a zero-valent nickel and an organophosphine or carbene ligand.

- The invention also relates to a process for the production of unsaturated nitrogen containing compounds comprising: reacting the salt of a compound  
25 containing an -NH- or -NH<sub>2</sub>- functional group next to a carbon sp<sup>2</sup> center with a compound of the formula



- where X is either chloride, bromide or iodide;  
R<sub>1</sub> is either hydrogen, an alkyl group or an aryl group;  
30 R<sub>2</sub> is independently selected from hydrogen, methyl or trimethylsilyl; and  
R<sub>3</sub> is an optionally substituted aryl group;

- in the presence of a catalytic amount of a catalyst precursor composition comprising a zero-valent nickel and an organophosphine or carbene ligand.

- 35 The unsaturated nitrogen containing compounds are preferably enamides, enamines, aryl amines or aryl amides.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Abbreviations used hereafter are listed and defined below as follows:

	CD <sub>3</sub> CN	Acetonitrile-d <sub>3</sub>
	NO <sub>2</sub> CD <sub>3</sub>	Nitromethane-d <sub>3</sub>
5	COD	1,5-Cyclooctadiene
	DBU	1,8-Diazabicyclo[5.4.0]undec-7-ene
	DBN	1,5-Diazabicyclo[4.3.0]non-5-ene
	DMF	Dimethylformamide
	DMSO	Dimethyl sulfoxide
10	KO <sup>t</sup> Bu	Potassium tert-butoxide
	Pcy <sub>3</sub>	Tricyclohexylphosphine
	P(naph) <sub>3</sub>	Tri(1-naphthyl)phosphine
	P(otol) <sub>3</sub>	Tri(o-tolyl)phosphine
	THF	Tetrahydrofuran
15	NMP	N-methyl-2-pyrrolidinone

The following terms as used herein are defined as follows:

“Alkyl” means an alkyl group up to and including 12 carbons. Common examples of such alkyl groups include methyl, ethyl, propyl, isopropyl, butyl, s-butyl, isobutyl, pentyl, neopentyl, hexyl, heptyl, isoheptyl, 2-ethylhexyl, cyclohexyl and octyl.

“Aryl” means a group defined as a monovalent radical formed conceptually by removal of a hydrogen atom from a hydrocarbon that is structurally composed entirely of one or more benzene rings. Common examples of such hydrocarbons include benzene, biphenyl, terphenyl, naphthalene, phenyl naphthalene, and naphthylbenzene.

“Heteroaryl” refers to unsaturated rings of 5 or 6 atoms containing one or two O and S atoms and/or one to four N atoms provided that the total number of hetero atoms in the ring is 4 or less, or bicyclic rings wherein the five or six membered ring containing O, S, and N atoms as defined above is fused to a benzene or pyridyl ring. Common examples are furan and thiophene.

“Hydrocarbyl” means a monovalent group containing only carbon and hydrogen, and may be chiral or achiral. Unless otherwise stated, it is preferred that hydrocarbyl (and substituted hydrocarbyl) groups contain 1 to 30 carbon atoms.

“Substituted” means a group that is substituted and contains one or more substituent groups that do not cause the compound to be unstable or unsuitable for the use or reaction intended. Substituent groups which are generally useful include nitrile, ether, ester, halo, amino (including primary, secondary and tertiary amino), hydroxy, oxo, vinylidene or substituted vinylidene, silyl or substituted

silyl, nitro, nitroso, sulfinyl, sulfonyl, sulfonic acid alkali metal salt, boranyl or substituted boranyl, and thioether.

By an "inert functional group" is meant a group such as acyl [-C(O)-alkyl] which does not cause the appropriate compound to be unstable or unsuitable for its use. A typical definition of a functional group may be found in R. T. Morrison, et al., Organic Chemistry, 6th Ed., Prentice Hall, Englewood Cliffs, NJ, 1992, p. 167-168 the contents of which are incorporated herein.

The phrase "more electronegative than carbon" as measured by the familiar Pauling Electronegativity Scale, see for instance J. E. Huheey, Inorganic Chemistry, 2nd Ed., Harper and Row, New York, 1978, p. 162. Also included within the definition of "more electronegative than carbon" are groups that are effectively more electronegative than carbon even though the atom bound directly to the imidazole ring may by itself not be more electronegative than carbon. See for instance J. E. Huheey, Inorganic Chemistry, 2nd Ed., Harper and Row, New York, 1978, p. 164. An atom that is more electronegative than carbon is bound to the carbon atom at the 4 or 5 position of the imidazole ring.

In Formulas I-V and other carbenes disclosed herein, the "colon" at the two position of the ring represents the two electrons of the carbene group.

The instant invention allows for the one step coupling of either a vinyl halide or an aryl halide with an -NH- containing compound in the presence of a catalytic amount of a zero-valent nickel organophosphine or zero-valent nickel carbene complex and a stoichiometric amount of a base. Alternatively, the salt of the -NH- containing compound can also be coupled with the vinyl, heteroaryl or aryl halide in the presence of a catalytic amount of a zero-valent nickel organophosphine or zero-valent nickel carbene complex but in the absence of a base. As used herein, a "catalytic amount" is defined as no more than 75% of the stoichiometric amount.

The -NH- containing substrates of the invention are generally defined as compounds containing an -NH- or -NH<sub>2</sub> functional group next to a carbon sp<sup>2</sup> center. Examples include primary and secondary amides, anilines, imidazoles, carbamates, amidines, guanidines, amino thiazolines, and ureas. Preferred are amides, imidazoles, and carbamates. However, compounds derived from coupling an alkylamine (e.g., dimethylamine) with a vinyl halide (e.g., styryl bromide) can also be produced. For instance, for -NH- substrate 15 set forth below, dimethylamine originates from the catalyzed decomposition of the DMF solvent.

The vinyl halide substrate of the invention is of the formula  $R_1R_2C=CR_2X$  where X is either chloride, bromide or iodide, R<sub>1</sub> is either hydrogen, an alkyl group, an aryl group, or an heteroaryl group, and R<sub>2</sub> is

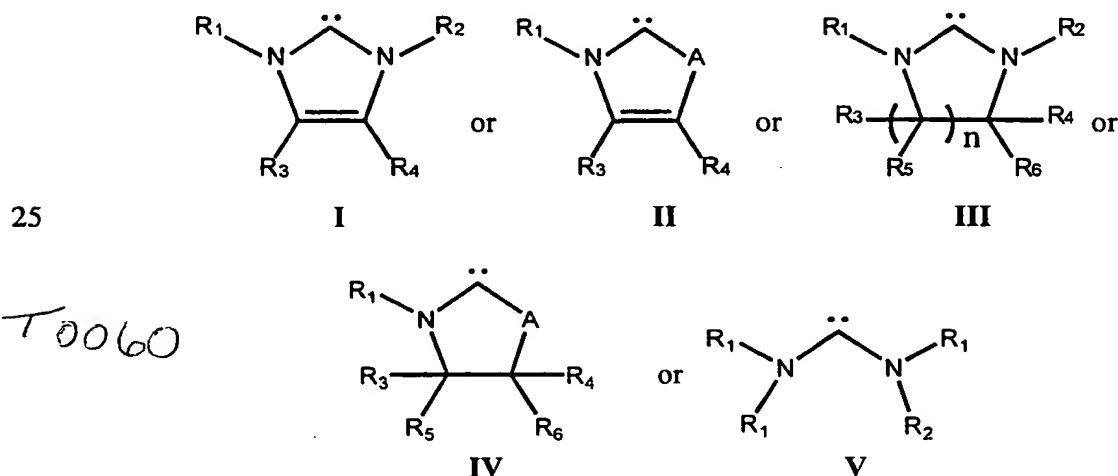
independently selected from hydrogen, methyl or trimethylsilyl. Alkyl groups can be straight chain or branched. In a preferred embodiment, X is bromide,  $R_1$  is phenyl (Ph) and both of  $R_2$  are hydrogen.

The aryl halides are of the formula  $R_3-X$  where  $R_3$  is an optionally substituted aryl group and X is Cl, Br or I. Optional substitutions on the aryl group include, but are not limited to, alkyl, phenyl, alkyl or aryl ether, thioether, and halogen and halogenated alkyl groups. In a preferred embodiment, X is iodide and  $R_3$  is a phenyl group which bears an electron-withdrawing substituent such as  $CF_3$ .

The zero-valent nickel organophosphine catalysts comprise a zero-valent nickel complexed with an organophosphine ligand, optionally prepared in-situ. The organophosphine ligand preferably comprises a trialkyl phosphine, substituted triaryl phosphine, or a tris-heteroaromatic phosphine. Alternatively, it can also be a mixed P-N or P-S ligand where N is imine, pyridine or amine; S is a thioether, and P is one of the organophosphine groups already described. The organophosphine ligand can be either monodentate or polydentate.

Preferred embodiments include large, bulky phosphine groups such as tricyclohexylphosphine, tri(1-naphthyl)phosphine, and tri(o-tolyl)phosphine. Most preferred embodiments include large, bulky electron-rich phosphine groups such as tricyclohexylphosphine.

The zero-valent nickel carbene catalysts of the invention comprise a zero-valent nickel complexed with a carbene ligand, optionally prepared in-situ. The carbene are compounds according to Formulas I-V set forth below:



wherein:

$R^1$  and  $R^2$  are each independently hydrocarbyl or substituted hydrocarbyl;

$R^3$ ,  $R^4$ ,  $R^5$  and  $R^6$  are independently an element more electronegative than carbon, a substituted element more electronegative than carbon, hydrogen, hydrocarbyl, substituted hydrocarbyl or an inert functional group;

n is an integer from 1 to 4; and

5 A is S or O.

Preferred carbene ligands are those of Formulas I, II and III. More preferred are those of Formula I. Most preferred carbene ligands are those of Formula I where  $R^1$  and  $R^2$  are methyl, mesityl, or adamantane, and  $R^3$  and  $R^4$  are independently hydrogen or methyl.

10 The carbene ligands can be prepared or generated using techniques well known in the art (e.g., for imidazol-2-ylidenes see Arduengo, A. J. III, et. al., J. Am. Chem. Soc., 1994, 116, p 4391; for imidazol-2-ylidenes and larger saturated systems see Arduengo, A. J., III, et al., J. Am. Chem. Soc., 1995, 117, p 11027; for acyclic diaminocarbenes see Alder, R. W et al., Angew. Chem., 1996, 108, p 1211; for benzoxazol-2-ylidenes and oxazol-2-ylidenes see 15 Hahn, F. E., Tamm, M. J., Organomet. Chem. 1993, 456, pg. C11; for thiazol-2-ylidenes see Arduengo, A. J., III et al., Liebigs Ann., 1997, p 365; for cyclopropen-2-ylidenes see Tamm, M et al., J. Organomet. Chem. 1995, 501, p 309; for monoaminocarbene complexes see Gabor, B et al., Angew. Chem., 20 Int. Ed. Engl. 1991, 30, p 1666; and for a general review of metal-carbene complexes see Lappert, M. F., J. Organomet. Chem. 1988, 358, p 185; all of which are herein incorporated by reference).

The zero-valent nickel catalyst can be prepared or generated using techniques well known in the art (see, e.g., U.S. Patent Nos. 3,496,217, 25 3,631,191, 3,846,461, 3,847,959, and 3,903,120 which are herein incorporated by reference). Zero-valent nickel compounds that contain ligands which can be displaced by the claimed ligand are the preferred source of zero-valent nickel. One such preferred zero-valent compound is  $Ni(COD)_2$  which is well known in the art. Alternatively, divalent nickel compounds may be combined with a 30 reducing agent and are then able to serve as suitable sources of nickel in the reaction. Suitable divalent nickel compounds include compounds of the formula  $NiY_2$  where Y is halide, carboxylate, or acetylacetonate. Suitable reducing agents include metal borohydrides, metal aluminum hydrides, metal alkyls, Zn, Fe, Al, Na, and  $H_2$ . Elemental nickel, preferably nickel powder, when 35 combined with a halogenated catalyst such as described in U.S. Patent No. 3,903,120 is also a suitable source of zero-valent nickel. Divalent nickel compounds of the formula  $NiLRBr$  or  $NiL_2RBr$  where L is an organophosphine or carbene ligand of the groups defined above and R is either an aryl or a vinyl group are also suitable sources of zero-valent Ni catalyst.

The reaction can be run in solution phase with a stoichiometric amount of a base of basicity equal or greater than about 20 pK<sub>a</sub> in acetonitrile. Generally, temperatures of between about 50-150°C can be used for the reaction. Suitable non-limiting solvents include toluene, DMF, xylene, DMSO, THF, acetonitrile and nitromethane.

Presently preferred embodiments of the instant invention include in molar parts: 5 parts Ni(COD)<sub>2</sub>, 10 parts Pcy<sub>3</sub>, 100 parts styryl bromide, 200 parts of the -NH- containing substrate and 200 parts KO<sup>t</sup>Bu in DMF at about 80-130°C; or alternatively, 5 parts Ni(COD)<sub>2</sub>, 10 parts Pcy<sub>3</sub>, 100 parts styryl bromide, 200 parts of the -NH- containing substrate and 200 parts DBU in toluene at about 100-130°C.

### EXAMPLES

All of the following non-limiting examples were conducted in the same manner and on the same scale as Example 1 provided below for reactions using DBU or DBN as the base, or as Example 2 for reactions using KO<sup>t</sup>Bu as the base, with the exception of Examples 94-126, as described below. The same catalyst was used for all examples except as specifically noted below. The substrates listed in the tables are shown below and are identified in the tables by caption number. Isomers identified in the tables are the cis/trans (E/Z) isomers which are illustrated as "~~~~~" in the chemical structures. Where only one product was identified, it was assumed to be the trans isomer as over time, all the isomeric mixtures identified tended to isomerize to the trans.

Product yields, as measured by gas chromatographic analysis (GC), only include the -NH- products that are neutral at the end of the reaction. When anionic products were formed, the reaction mixture was treated with hydrochloric acid and the product reanalyzed by GC. Where this was performed, the resulting numbers are denoted by an "\*" in the tables. All percentages are expressed as mol percent unless otherwise specified.

#### EXAMPLE 1

200 µl of a 1.0 M solution of trifluoroacetamide in DMF and 400 µl of a 0.2 M solution of β-bromostyrene in DMF were placed in a glass vial. 27 mg (0.24 mmol) KO<sup>t</sup>Bu were added followed by addition of 200 µl of the catalyst solution. The catalyst solution was formed by combining 0.04 M Ni(COD)<sub>2</sub> and 0.08 M Pcy<sub>3</sub> in a 1:2 toluene/DMF solution. A color change indicating complex formation was seen when the catalyst solution was prepared, consistent with the results reported in the art. The reaction mixture was heated at 85°C for 1.5 hrs. GC and GC/MS (mass spectroscopy) analysis showed 98% conversion to 2,2,2-trifluoro-N-(2-phenylethenyl)-acetamide.

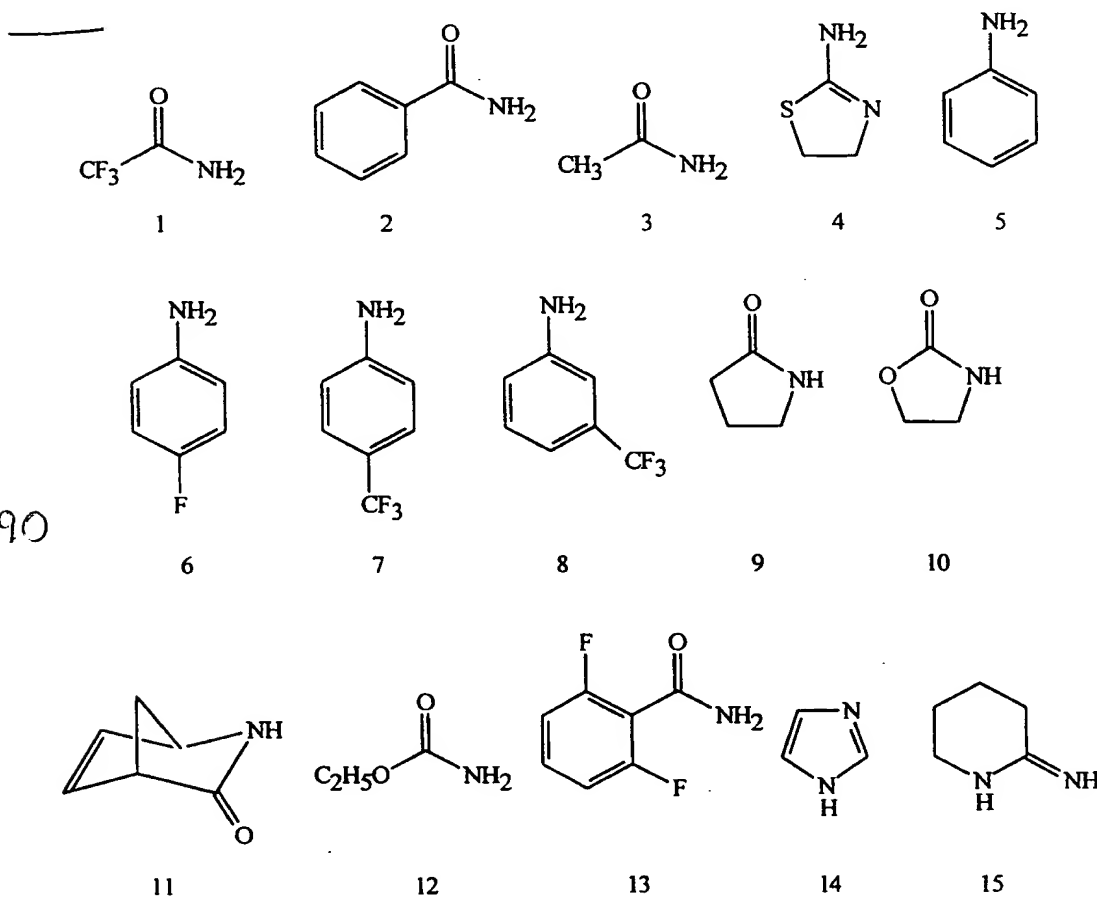
EXAMPLE 2

16 mg (0.73 mmol) of p-iodotoluene, 16 mg (0.18 mmol) 2-oxazolidinone, and 31 mg (0.20 mmol) DBU were dissolved in 2 ml toluene. 0.5 ml of the catalyst solution was added. The catalyst solution was formed by combining 2 mg  $\text{Ni}(\text{COD})_2$  and 8.1 mg  $\text{M Pcy}_3$  in 0.5 ml of toluene. A color change indicating complex formation was seen when the catalyst solution was prepared, consistent with the results reported in the art. The reaction was then heated at 100°C for 30 hrs. GC and GC/MS analysis showed 22% conversion to 3-(4-methylphenyl)-2-oxazolidinone.

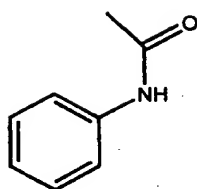
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EXAMPLES 3-93NH Substrates (-NH-containing compounds)

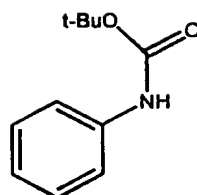
The following additional -NH- substrates were used in the tables provided below:







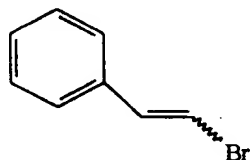
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X Substrates (Vinyl halides or aryl halides)

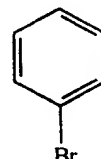
The following additional X substrates were used in the tables provided below:



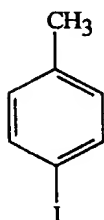
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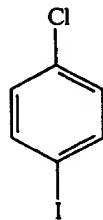
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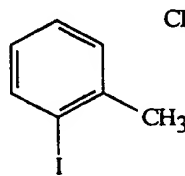
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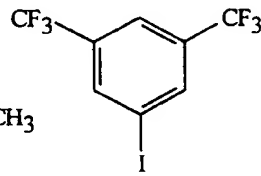
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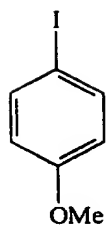
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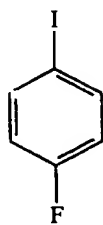
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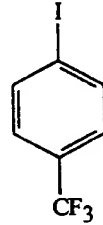
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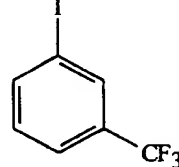
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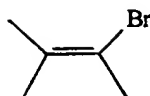


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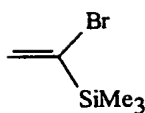


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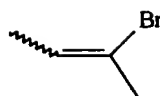
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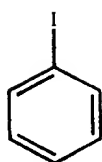
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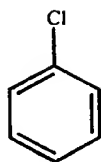
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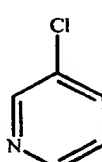
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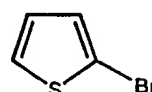
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xvi



xvii



xviii

TABLE I

Example	X	NH	Base	Solvent	Temp., °C	Time, hrs.	Product Yield(%) -mol	Comments	Notes
3	i	1	DBU	Toluene	105	15	17.3	2 isomers	
4	i	1	DBU	THF	105	15	21.3	2 isomers	
5	i	1	DBU	CD <sub>3</sub> CN	105	15	31.1	2 isomers	
6	i	1	DBU	NO <sub>2</sub> CD <sub>3</sub>	105	15	43.0	1 product	
7	i	1	DBU	DMF	120	16	11.3	2 isomers	a
8	i	1	DBU	Xylene	120	16	18.5	2 isomers	b
9	i	1	DBU	Xylene	120	16	9.9	2 isomers	c
10	i	1	DBN	Xylene	120	16.5	26.0	2 isomers	
11	xviii	5	DBU	Toluene	150	48	40	1 product	
12	i	2	DBU	Xylene	130	16.5	12.4	2 isomers	
13	i	16	DBU	Toluene	110	70	50	2 isomers	
14	i	2	DBU	DMF	130	16.5	12.7	2 isomers	
15	i	17	KO <sup>t</sup> Bu	DMF	110	40	50	2 isomers	
16	i	2	DBU	DMF	130	16.5	12.2	2 isomers	d
17	i	2	DBU	DMF	130	39	13.8	2 isomers	d
18	i	2	DBU	Xylene	120	31	27.8	2 isomers	
19	i	2	DBU	Xylene	130	41	11.2	2 isomers	
20	i	2	DBU	Xylene	140	41	6.8	2 isomers	
21	i	3	DBU	Toluene/THF	110	132	8.0	2 isomers	
22	i	4	DBU	Xylene	120	17	4.5	2 isomers	
23	i	4	DBU	Xylene	120	90	4.5	2 isomers	
24	i	9	DBU	Xylene	120	17	9.9	2 isomers	
25	i	9	DBU	Xylene	120	90	21.2	2 isomers	
26	ii	1	DBU	Toluene-d <sub>8</sub>	105	49.5	2.4	1 product	e
27	iv	1	DBU	Xylene	115	17	13.7	1 product	

Example	X	NH	Base	Solvent	Temp., °C	Time, hrs.	Product Yield(%) -mol	Comments	Notes
28	iv	1	DBU	Xylene	115-120	64	6.8	1 product	
29	v	1	DBU	Xylene	115	17	0.96	1 product	
30	v	1	DBU	Xylene	115-120	64	1.3	1 product	

TABLE II

Example	X	NH	Base	Solvent	Temp., °C	Time, hrs.	Product yield(%) -mol	Comments	Notes
31	vi	1	DBU	Xylene	115	17	1.3	1 product	
32	vi	1	DBU	Xylene	115-120	64	1.0	1 product	
33	vi	1	DBU	Xylene	115	17	10.9	1 product	
34	vi	1	DBU	Xylene	115-120	64	12.8	1 product	
35	i	1	DBU	Toluene	85	44	14.5	2 isomers	
36	i	10	DBU	Toluene	100	60	43.4	1 product	
37	i	11	DBU	Toluene	100	60	15.6	1 product	
38	i	9	DBU	Toluene	100	60	4.5	1 product	
39	i	6	DBU	Toluene	100	44	43.5	1 product	
40	i	8	DBU	Toluene	100	44	10.0	1 product	
41	i	2	DBU	Toluene	100	44	10.0	2 isomers	
42	i	3	DBU	Toluene	100	44	12.0	1 product	
43	iv	10	DBU	Toluene	100	30	22.0	1 product	
44	iv	11	DBU	Toluene	100	30	3.2	1 product	
45	iv	6	DBU	Toluene	100	30	14.5	1 product	
46	iv	7	DBU	Toluene	100	30	5.1	1 product	
47	iv	8	DBU	Toluene	100	30	7.4	1 product	
48	iv	1	DBU	Toluene	100	44	18.0	1 product	
49	iv	2	DBU	Toluene	100	110	26.0	1 product	
50	iii	1	DBU	Toluene	85	20	4.1	1 product	
51	iii	2	DBU	Toluene	100	44	7.7	1 product	
52	iii	3	DBU	Toluene	100	44	9.3	1 product	
53	iii	2	DBU	Toluene	80	44	7.0	2 isomers	
54	ii	10	DBU	Toluene	100	30	6.2	1 product	
55	ii	6	DBU	Toluene	100	30	14.9	1 product	
56	i	10	DBU	Toluene	60	1	71	1 product	
57	xii	10	DBU	Toluene	100	42	26		

Example	X	NH	Base	Solvent	Temp., °C	Time, hrs.	Product yield(%)—mol	Comments	Notes
58	xiv	10	DBU	Toluene	100	42	20		
59	xiii	10	DBU	Toluene	100	42	21		
60	xiv	10	DBU	Toluene	100	42	20		

TABLE III

Example	X	NH	Base	Solvent	Temp., °C	Time, hrs.	Product yield(%)— mol	Comments	Notes
61	vi	1	KO <sup>t</sup> Bu/0.5,18-crown-6	Xylene	120	18	7.2	2 isomers	
62	i	1	KO <sup>t</sup> Bu/1,18-crown-6	Xylene	120	16	16.2	2 isomers	
63	i	1	KO <sup>t</sup> Bu/2,18-crown-6	Xylene	120	16	0.33	2 isomers	
64	i	1	KO <sup>t</sup> Bu/3,18-crown-6	Xylene	120	16	7.5	2 isomers	
65	i	2	KO <sup>t</sup> Bu	DMF	110	5	40.0	2 isomers	
66	i	2	KO <sup>t</sup> Bu/2,18-crown-6	Toluene	110	5	23.0	2 isomers	
67	i	2	KO <sup>t</sup> Bu	DMF	110	17	6.10 (90.8)*	2 isomers	
68	i	2	KO <sup>t</sup> Bu/2,18-crown-6	Toluene	110	17	43.8 (86.8)*	2 isomers	
69	i	1	KO <sup>t</sup> Bu	THF/ 1% <sup>H</sup> <sub>2</sub> O	105	15	18.1	2 isomers	
70	i	1	KO <sup>t</sup> Bu	DMF	110	5	65.8	2 isomers	
71	i	1	KO <sup>t</sup> Bu	DMF	110	17	54.7 (91.4)*	2 isomers	
72	i	1	KO <sup>t</sup> Bu	DMSO	80	0.5	54*		
73	i	1	KO <sup>t</sup> Bu	DMSO	80	2.5	57.6*		
74	i	1	KO <sup>t</sup> Bu	DMSO	80	4	53*		
75	i	1	KO <sup>t</sup> Bu	NMP	80	0.5	8.4*		
76	i	1	KO <sup>t</sup> Bu	NMP	80	1.5	15.2*		
77	i	1	KO <sup>t</sup> Bu	NMP	80	2.5	39.8*		
78	i	1	KO <sup>t</sup> Bu	NMP	80	4	39.8*		
79	i	1	KO <sup>t</sup> Bu	DMF	85	0.5	69*		
80	i	1	KO <sup>t</sup> Bu	DMF	85	1.5	82*		
81	i	1	KO <sup>t</sup> Bu	DMF	85	2.5	98*		
82	i	1	KO <sup>t</sup> Bu	DMF	85	3.5	98*		
83	i	2	KO <sup>t</sup> Bu	DMF	85	0.5	95*		

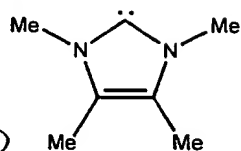
Example	X	NH	Base	Solvent	Temp., °C	Time, hrs.	Product yield(%) -mol	Comments	Notes
84	i	2	KO <sup>t</sup> Bu	DMF	85	1.5	90*		
85	i	2	KO <sup>t</sup> Bu	DMF	85	2.5	95*		
86	i	2	KO <sup>t</sup> Bu	DMF	85	3.5	95*		
87	i	12	KO <sup>t</sup> Bu	DMF	110	20.5	18.0		
88	i	12	KO <sup>t</sup> Bu	DMF	110	86.5	16.5*		
89	i	13	KO <sup>t</sup> Bu	DMF	110	20.5	50.0		
90	i	13	KO <sup>t</sup> Bu	DMF	110	86.5	44*		
91	i	14	KO <sup>t</sup> Bu	DMF	110	21	20.8		
92	i	15	KO <sup>t</sup> Bu	DMF	100	16	54		f
93	i	15	KO <sup>t</sup> Bu	DMF	100	40	49*		f

TABLE NOTES

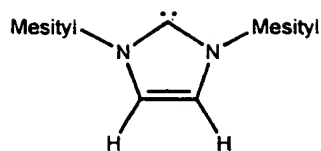
- 5 a. The catalyst used in the reaction was 1 equivalent P(o-tol)<sub>3</sub> to 1 equivalent Ni(COD)<sub>2</sub>.
- b. The catalyst used in the reaction was 2 equivalents P(o-tol)<sub>3</sub> to 1 equivalent Ni(COD)<sub>2</sub>.
- c. The catalyst used in the reaction was 3 equivalents P(o-tol)<sub>3</sub> to 1 equivalent Ni(COD)<sub>2</sub>.
- 10 d. 1 equivalent [CH<sub>3</sub>(CH<sub>2</sub>)<sub>3</sub>]<sub>4</sub>NBr to 1 equivalent Ni(COD)<sub>2</sub> was added to the starting system.
- e. The ratio of the R<sub>3</sub>-X to -NH- was 3:1. The product was N,N' disubstituted.
- f. The product is styryldimethylamine derived from coupling of dimethylamine with styrylbromide. Dimethylamine originates from the catalyzed
- 15 decomposition of the DMF solvent.

EXAMPLES 94-126

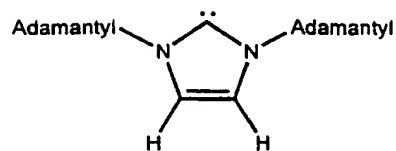
- Examples 94-126 were run similar to Example 2 except for the following changes. Unless noted differently, a 10% (mole percent) catalyst loading of nickel carbene complex was used. The catalyst was generated in situ by mixing
- 20 Ni(COD)<sub>2</sub> and carbene in a 1:1 ratio. The reaction mixture was heated at 85°C overnight and the products analyzed by GC. Carbene ligands used are as follows:



I



II



III

TABLE IV

Example	X	NH	Ligand	Product yield(%) -mol	Notes
94	i	10	I	>98	
95	"	"	II	>98	
96	"	"	III	>98	
97	i	5	I	>98	a
98	"	"	II	>98	a
99	"	"	III	>98	a
100	i	1	I	>98	b
101	"	"	II	93	b
102	"	"	III	95	b
103	i	10	I	12	
104	"	"	II	36	
105	"	"	III	14	
106	iii	5	I	68	
107	"	"	II	92	
108	"	"	III	29	
109	iii	1	I	32	
110	"	"	II	20	
111	"	"	III	12	
112	xv	10	I	27	
113	"	"	II	>98	
114	"	"	III	24	
115	xv	5	I	40	
116	"	"	II	36	
117	"	"	III	7	
118	xv	1	I	29	
119	"	"	II	37	
120	"	"	III	20	
121	xvi	1	II	0	
122	xvii	1	II	0	
123	xvi	10	II	10%	

Example	X	NH	Ligand	Product yield(%)- mol	Notes
124	xvii	10	II	5%	
125	xvi	5	II	40%	
126	xvii	5	II	40%	

TABLE NOTES

- a. GC integration unclear
- 5 b. Product peak in GC overlapped by DBU peak - verified by running with DBN as the base

The inventive examples indicate that zero-valent nickel complexes are catalytic in nature rather than stoichiometric and that one step coupling of vinyl halides and aryl halides can occur.

10 COMPARATIVE EXAMPLES (A-E)

- Comparative examples of the prior art (A-C) were conducted in the same manner as the previous inventive examples except for the use of 5% CuBr(CH<sub>3</sub>)S complex with 10% Pcy<sub>3</sub> instead of Ni(COD)<sub>2</sub> complex. The low yields indicate that Cu(I) systems, as taught in the art, are stoichiometric rather
- 15 than catalytic. Additional comparative examples of the prior art (D-E) were conducted in the same manner as the previous inventive examples except for the use of Pd(0) complex with Pcy<sub>3</sub> instead of Ni(COD)<sub>2</sub> complex. The absence of product indicates that Pd phosphine complexes, as taught in the art, do not allow for one step coupling of vinyl halides and amides.

20

TABLE IV

Comp. Example	X	NH	Base	Solvent	Temp., °C	Time, hrs.	Product yield(%)- mol	Comments	Notes
A	i	1	DBU	Xylene	120	14	0.46	2 isomers	
B	iii	1	DBU	Xylene	120	14	2.30	1 product	
C	iii	1	DBU	Xylene	120	36.5	3.40	1 product	
D	i	1	KO <sup>t</sup> Bu	DMF	85	19	0		
E	i	1	KO <sup>t</sup> Bu	DMF	85	86	0		

Although particular embodiments of the present invention have been described in the foregoing description, it will be understood by those skilled in the art that the invention is capable of numerous modifications, substitutions and

25 rearrangements without departing from the spirit or essential attributes of the

invention. Reference should be made to the appended claims, rather than to the foregoing specification, as indicating the scope of the invention.

SECRET "TOP SECRET"